REFURBISHMENT OF THE ETDL REP-RATE PULSE GENERATOR AT AFRL

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Abstract

The Air Force Research Laboratory is refurbishing a high-voltage rep-rate pulser that generates 550 kV output pulses with a nominal FWHM of 550 ns at pulse repetition rates of up to 5 Hz. This pulser was originally constructed for the Army Research Laboratory's Electronic Test Devices Laboratory (ETDL). The pulser can drive 20-, 10-, or 5-Ω loads when either one, two, or four 20-Ω PFN's, respectively, are installed.

Among the major changes and upgrades that are being made to the pulser is the replacement of the output switch with a triggered cascade switch. Initially, a two-electrode self-breaking spark gap was used for the output switch, but this had jitter in pulse-to-pulse timing and waveshape due to variation in the self-break voltage. An earlier implementation of a triggered output switch was successful in reducing pulse-to-pulse jitter [1], but the spread still remained approximately 500 ns. A significant effort was directed during this present upgrade towards the development of an improved triggered output switch. The new switching system has a 10 ns total spread in breakdown time with respect to the initial trigger to the pulser system and provides reproducible waveshapes. The charging system has also been upgraded. The original system used a computer-controlled high-voltage DC power supply and a filter bank that pulse-charged the pulse generator's primary bank. This is being replaced with a commercially available, high-power (100 kV) DC charging supply to directly charge the primary bank. Eliminating the filter bank has led to a substantial reduction in size. Other modifications to the pulser include changes to the PFN design to allow greater ease and flexibility when tuning the pulse shape and to reduce the self-inductance of the PFN capacitors. This paper describes these modifications to the ETDL pulse generator in detail and presents data from initial tests following the upgrades.

I. INTRODUCTION

In the early 1990's Maxwell Laboratories, Inc. was contracted by the Army's Harry Diamond Laboratory (HDL) and the Electronics Technology and Devices Laboratory (ETDL) to develop a rep-rate pulser system that would serve as a user facility for the Army [2,3]. This pulser was later transferred to the Air Force Philips Laboratory (now the Air Force Research Laboratory) where it underwent a series of modifications to both increase maximum pulse repetition rate [4] and decrease output pulse jitter (total spread) by command triggering the output switch [1]. Use of this triggered output switch led to a significant improvement in pulser operation, but a jitter of ~500 ns still remained.

Recently, the "ETDL pulser" has undergone another series of modifications and refurbishments to prepare it for use as a replacement to the single-shot IMP pulser at AFRL [5]. The ETDL pulser's rep-rate capability and its smaller footprint make it an ideal candidate. Refurbishment efforts have been focused on improving PFN characteristic pulse shape and on installing an advanced triggered output switch to further reduce jitter and amplitude variations in the output pulse. A larger set of current and voltage diagnostics were also installed to better characterize and monitor pulser performance.

Section II of this paper discusses the modifications made to the PFN and describes the new triggered output switch. Section III then highlights some of the results from tests performed with the pulser throughout the refurbishment process. Lastly, a short summary of this work is given in Section IV, along with a brief description of a few remaining tests needed to complete this work.

II. MODIFICATIONS TO PULSER

The original ETDL pulser system consisted of a command charging unit, a control rack, the pulser itself in an oil-filled vessel, and a computer controller [2,3]. Our

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tests to date have been limited to manual controls, and the primary bank has been charged directly with a small 100 kV, 5.5 mA power supply. As a result, only single-shot tests have been performed thus far. The output impedance of the pulser is variable – 20, 10, or 5 Ω depending on whether one, two, or four PFN's are connected between the pulse transformer and the output switch. Tests have been conducted with a single 20-Ω PFN at this time, since this driver impedance is planned for initial operation.

Diagnostics for the pulser include a variety of voltage and current probes to monitor points in the pulser circuit. In addition, several open-ended fiber optic lines (connected to PIN diodes) are used to determine the times at which light appears in the trigger isolation gap and in selected gaps in the cascade switch.

A. Adjusting PFN Stage Inductance

Two modifications were made to the PFN design to increase the flexibility in tuning the inductances of each stage and to optimize the output pulse shape. The first modification involved replacing the original rigid PFN inductor network, consisting of pairs of parallel square loops fabricated from 2.5-cm (1-in.) diameter copper pipe, with one or two split metal rings on each PFN stage. The rings are made from aluminum pipe with a 14 cm (5.5 in.) outer diameter and a 1.3 cm (0.5 in.) wall thickness.

A single ring having an axial length of 6.4 cm (2.5 in.) is placed on the two or three stages closest to the pulse transformer to provide a ~100-nH stage inductor. Two rings, each with an axial length of 3.8 cm (1.5 in.) and a center-to-center spacing of nominally 8.9 cm (3.5 in.), are used to form a ~280 nH inductor for the remaining stages. Figure 1 shows a photo of the PFN with the split rings in place on the capacitors. Unlike the copper pipe inductor, in which the loops in each stage were connected in parallel, the split rings are connected in series to emulate a helix. Decreasing the center-to-center spacing increases the effective inductance and vice versa. Coupling between stages can be adjusted by slightly rotating the rings on a given stage about their vertical axis.

A second modification to the PFN involved the placement of vertical ground planes on each side of the PFN that fan up and out from the base. Stage inductance is influenced by the distance between the capacitor pads and the pulser ground plane, so extending the ground plane upwards affords a way of reducing the ~350 nH of

series inductance in the PFN capacitors and its effect on the PFN pulse shape. Conceivably, the ground planes could also be extended up and over the PFN (i.e., wrapped around the PFN) in the form of a mesh to reduce inductance even further, however this concept has not yet been tested.

B. Installation of Triggered Cascade Switch

The most significant upgrade on the ETDL pulser is its new triggered cascade output switch. This switch is identical to one recently installed on the Rep-rate Test Pulser (RTP) [6], on which it was shown to have a jitter of 10's of nanoseconds and reliable operation for several 100's of thousands of shots with little or no maintenance.

The cascade switch consists of a stack of ten segments, where a segment is an electrode pair separated by a polycarbonate insulator. Each electrode is supported with a mid-plane. The segments are internally light coupled with windows arranged along the axis so that UV radiation from the closure of one segment illuminates the contiguous segments. This is a factor in achieving a rapid cascade when the first or second mid-plane is triggered. In addition, an illuminating pin, resembling a spark plug, is located within the first segment to ensure the presence of UV radiation when the trigger pulse is applied. The applied voltage across the switch is resistively divided among the ten segments by 10-kΩ ceramic resistors placed across each segment. Both end plates of the switch are 30.5 cm (12 in.) in diameter and, with the ten segments between them, are spaced 40.6 cm (16 in.) apart. The entire assembly is held together with twelve 2.5-cm (1-in.) diameter Lexan tie rods. The switch rests on a PVC stand in the oil tank, with one end connected to the PFN output and the other to the high-voltage terminal of the load (Figure 2).

A circuit diagram of the trigger generator for the switch is shown in Figure 3. The trigger generator is a simple yet reliable thyratron-based system using a CX-1175 thyratron to switch the energy stored in a capacitor into the primary of a pulse transformer [7]. The transformer steps up the voltage of the pulse 12.5 times to deliver a 375 kV pulse to the first or second gap of the cascade switch and the illuminating pin. The 2.5 kΩ resistor holds
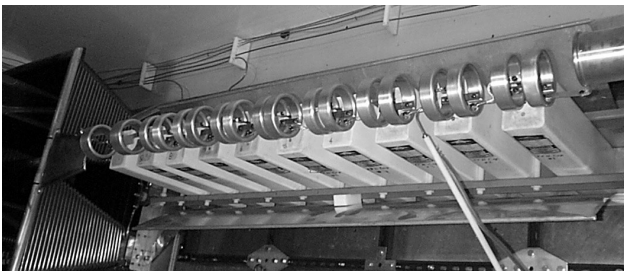

Figure 1.   Photo of the ETDL PFN showing the split-ring inductors on each capacitor and the ground planes flaring out on each side of the PFN from the base.
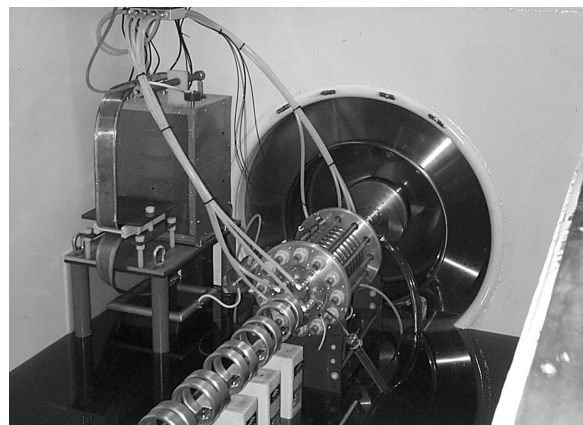

Figure 2.   The cascade switch and its triggering system in the ETDL oil tank after final setup was completed.

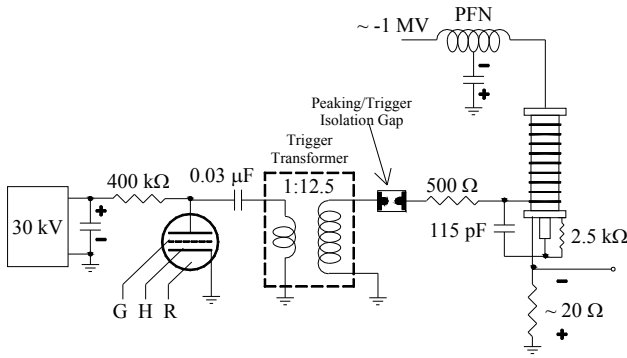Figure 3.   Schematic diagram of the triggering system for the ETDL cascade switch.

Figure 4.   PFN voltage waveforms from the final tabletop test (in V) and from Test Shot 129 (in kV).

the illuminating pin at the same potential as the load-side switch plate during the PFN charge time, and the 115 pF capacitance couples the pin to the first or second gap where the trigger pulse is applied.

III. PERFORMANCE OF PULSER

A. PFN Pulse Shape (Self-Break Output Switch)

Due to the somewhat tedious nature of the tuning process, initial tuning of the PFN was performed outside of the oil tank on a tabletop where all areas of the PFN were easily accessible. This tuning was performed at relatively low voltage (80 V), using a small power supply to charge the PFN directly and a mercury reed switch to switch the PFN to a matched (20 Ω) load. Load voltage was measured directly with a scope probe, and current was monitored with a Pearson 410 current probe.

Adjustments were made to the split-ring inductor spacing and vertical ground plane positions until the pulse shape was optimized with the shortest rise and fall times (~43 ns and ~165 ns, respectively) and maximum flatness on the top (+5 % over and -4 % under the mean value). The pulse FWHM was ~543 ns. The final configuration of the PFN consisted of two single-turn split rings at the transformer end of the PFN and split-ring pairs on the remaining stages. The spacing of the split-ring pairs was kept at ~8.9 cm (~3.5 in.) on the outer stages of the PFN but was decreased for the inner stages to raise inductance there.   Such an arrangement proved effective for improving the flatness of the top of the pulse.

Once tuning was completed, the PFN was placed in the oil tank, connected to the pulse transformer and output switch, and higher voltage tests were then performed to verify the pulse shape. The initial tests were still at low enough voltage that oil was not placed in the tank immediately; only when PFN voltage was expected to exceed ~120 kV was the tank filled. Fabrication of the cascade switch had not yet been completed at this time, so a self-breaking switch was used again in the interim.

Figure 4 shows the output voltage waveform from "Test Shot 129", where the PFN voltage reached -91 ~ -94 kV just before the output switch closed. The waveform from the final tabletop test is also shown here for comparison. Initially, it was anticipated that some additional tuning
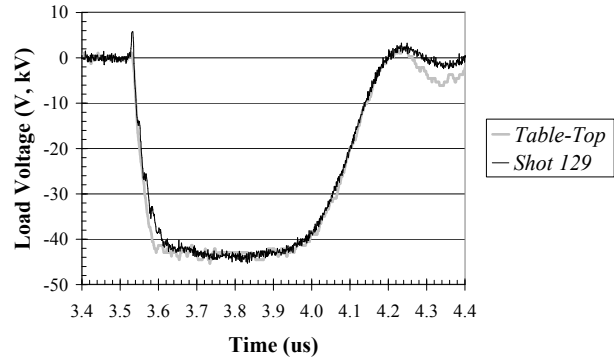
would be required after the PFN was integrated into the rest of the pulser, however there is minimal difference between the pulse shapes for these two cases. The rise time is slightly longer (due to the output switch inductance) for Test Shot 129, and the top of the pulse is slightly more rounded, but these features improved somewhat as the PFN voltage increased. For Test Shot 129, the variation in the pulse top is approximately +5 %, -7% about the mean value, the rise and fall times are ~62 ns and ~165 ns, respectively, and the FWHM is ~540 ns.

B. Cascade Switch Operation

Following characterization of the PFN and completion of the cascade switch fabrication, testing of the cascade switch's performance on the ETDL pulse generator then began. A set of light monitors, consisting of unterminated fiber optic lines running to PIN diode receivers, were set up when the switch was installed to verify switch closure during operation. Provision for a total of five such light monitors was made: one on the peaking/trigger isolation gap and four on different gaps of the cascade switch. Such monitors were used during the initial phase of testing with the RTP pulser's output switch and were found to be extremely helpful during troubleshooting [6].

After a few issues with surface tracking on the switch stand and nearby insulators were addressed, fifty-one full-voltage (V_{PFN} = -1.08 MV) shots were successfully conducted with the cascade switch, as well as a number of lower-voltage shots, without further problems.   In this series of shots six different trigger delays (with respect to primary switch closure) were investigated, and jitter, timing, and waveshape were measured. In particular, data from these shots were used to measure the jitter in the switch and its triggering system and to quantify the reproducibility of the output voltage waveforms.

A plot of four of the load voltage waveforms from shots in which the cascade switch was set to trigger at the peak PFN charge (~4.1 μs after primary switch closure) are shown in the graph in Figure 5. The jitter is observed to be ~65 ns here, and reproducibility of both the amplitude and pulse shape of the waveforms is quite good. Thirty-one of the fifty-one shots were performed with this delay; the overall jitter observed for all of these shots is ~90 ns. We note that a significant portion of the jitter is due to the thyratron and that the thyratron jitter can be reduced to
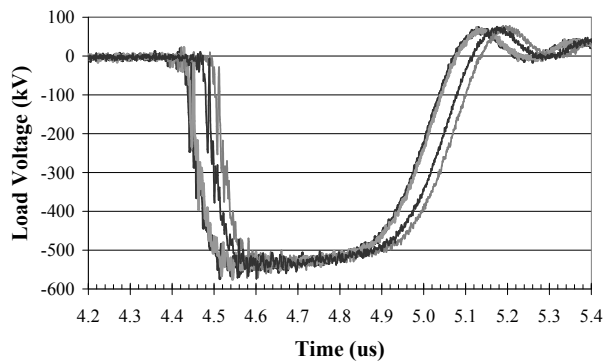
Figure 5. Four load voltage waveforms from test shots with the same cascade switch trigger delay.
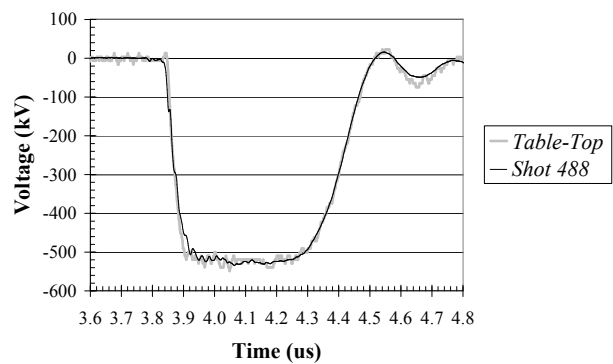

Figure 6. Graph of voltage waveforms from Test Shot 488 (cascade switch triggered 600 ns before PFN peak) and from the final tabletop test with the PFN (scaled).

negligible values by careful adjustment of the reservoir current and trigger input waveshape. This is planned for future testing.

For the remaining twenty full-voltage shots the delay was changed in 200-ns increments, ranging from 800 ns before peak PFN charge to 200 ns after. The change in cascade switch closure time was found to follow fairly closely (within ± ~20 ns). The slope of the pulse top was observed to change slightly during these tests, with the flattest pulses appearing when the switch was triggered 400 – 600 ns (i.e., one pulsewidth) before peak PFN charge. The change in slope is a result of the ongoing charging or discharging of the PFN through the pulse transformer while it is also being discharged into the load.

Figure 6 shows the load voltage waveform (smoothed) from Test Shot 488 for which the cascade switch was triggered ~600 ns before peak PFN charge. This trace is overlaid with the scaled voltage waveform from the final tabletop test, and as can be seen, the waveshapes are nearly identical. The rise time of the Test Shot 488 waveform is ~68 ns, the fall time ~168 ns, and the FWHM ~545 ns. The mean voltage of the pulse is ~ -524 kV, and the variation about this mean is +2.5%/-2.0%.

IV. SUMMARY

Through the use of the aluminum split-ring inductors and the vertical ground planes considerable flexibility has been added to the tuning of the ETDL pulse generator's PFN. While the ground planes may not be helpful for more compact PFN systems, where smaller (lower voltage) capacitors with lower series inductance are used or the oil tank walls are close enough to serve this purpose, their usefulness for large systems such as ours has clearly been demonstrated.

Of greater significance has been the demonstration of the very low-jitter operation of the triggered cascade switch at the ETDL pulser's output. Jitters of < 90 ns were observed, resulting in very minor changes in pulse shape from shot to shot. Much of this jitter lies with the trigger system, and the cascade switch itself has only a relatively small portion of this overall jitter. With further development work, implementation of a compact triggering system based upon a solid-dielectric-insulated

transformer is feasible, which would substantially reduce physical size.

A final series of tests to demonstrate the rep-rate capabilities of the ETDL cascade switch and its trigger system is planned. The rep-rate capabilities of the other components of the pulser have already been demonstrated at up to 40 Hz by Calico, et al. with a single 20-Ω PFN [1]. A 100-kV, 1-A power supply has recently been refurbished at the AFRL and should allow tests to be conducted to at least 3 or 4 Hz. These tests are planned for later this year.

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